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Particle-related exposure, dose and lung cancer risk of primary school children in two European countries

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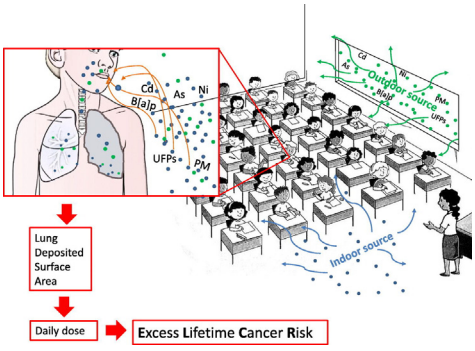
HIGHLIGHTS

- Exposure to airborne particles at schools in two Mediterranean cities in Europe
- Measured total particle surface area doses received at school by children
- Measured concentrations of As, Cd, Ni and B[*a*]p
- Evaluation of excess lung cancer risk

GRAPHICAL ABSTRACT



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ABSTRACT

Schools represent a critical microenvironment in terms of air quality due to the proximity to outdoor particle sources and the frequent lack of proper ventilation and filtering systems. Moreover, the population exposed in schools (i.e. children) represents a susceptible population due to their age. Air quality-based studies involving students' exposure at schools are still scarce and often limited to mass-based particle metrics and may thus underestimate the possible effect of sub-micron particles and particle toxicity.

To this purpose, the present paper aims to evaluate the exposure to different airborne particle metrics (including both sub- and super-micron particles) and attached carcinogenic compounds. Measurements in terms of particle number, lung-deposited surface area, and PM fraction concentrations were measured inside and outside schools in Barcelona (Spain) and Cassino (Italy). Simultaneously, PM samples were collected and chemically analysed to obtain mass fractions of carcinogenic compounds. School time airborne particle doses received by students in classrooms were evaluated as well as their excess lung cancer risk due to a five-year primary school period.

Median surface area dose received by students during school time in Barcelona and Cassino resulted equal to 110 mm^2 and 303 mm^2, respectively. The risk related to the five-year primary school period was estimated as about 2.9×10^{-5} and 1.4×10^{-4} for students of Barcelona and Cassino, respectively. The risk in Barcelona is slightly higher with respect to the maximum tolerable value (10^{-5}, according to the U.S. Environmental Protection Agency), mainly due to toxic compounds on particles generated from anthropogenic emissions (mainly

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industry). On the other hand, the excess lung cancer risk in Cassino is cause of concern, being one order of magnitude higher than the above-mentioned threshold value due to the presence of biomass burning heating systems and winter thermal inversion that cause larger doses and great amount of toxic compounds on particles.

1. Introduction

1.1. Airborne particle metrics

Particulate matter in outdoor air pollution is carcinogenic to humans (Group 1) as recently reported by the World Health Organization (International Agency for Research on Cancer, 2013; Loomis et al., 2013): indeed, overexposure to PM was estimated to cause about 2.1 million deaths per year world-wide (Silva et al., 2013). In addition, many studies also highlighted the link between PM and some adverse human health effects such as the increase of cardiovascular, cerebrovascular and respiratory mortality and morbidity (Auchincloss et al., 2008; Block and Calderón-Garcidueñas, 2009; Cesaroni et al., 2013; Chen et al., 2016a; Chen et al., 2016b; Pope and Dockery, 2006; Power et al., 2011). The harmful potential of the particles is related to their ability to penetrate in the deepest areas of human respiratory tract, carrying toxic compounds as heavy metals, polycyclic aromatic hydrocarbons and dioxin/furans, attached onto particle surface (Abdel-Shafy and Mansour, 2016; Eiguren-Fernandez et al., 2010; Li et al., 2015). In particular, the inhalation and consequent deposition of these compounds is strictly associated to the size of the carrying particles: higher deposition fractions in the lungs are characteristics of sub-micron and ultrafine particles (UFPs, particles with a diameter <100 nm) (International Commission on Radiological Protection, 1994). Moreover, smaller particles were also recognized to translocate from lungs to the cardiovascular system and from there to other organs (liver, spleen, kidneys, brain) (Campagnolo et al., 2017; Nakane, 2012; Peters et al., 2006). A few studies have been carried out on the association of ultrafine particles and premature mortality and the results are inconclusive using number concentration data (Atkinson et al., 2010; Health Effects Institute, 2013; Lanzinger et al., 2016; Stafoggia et al., 2017). On the other hand, several studies reported evidences of health outcomes associated to black carbon (a component of ultrafine particles) (Ostro et al., 2015). Thus, even if conclusive results were not provided by the scientific community, sub-micron and ultrafine particles, whose characteristic metrics are particle number and surface area concentrations, represent the most promising particle size ranges in terms of health effect evaluation (Buonanno et al., 2013; Franke et al., 2011; Giechaskiel et al., 2009). In particular, several studies recently highlighted that dose-response correlation in terms of health effects is better related to surface area of particles deposited in the lungs than other metrics of exposure: summarizing, particle surface area is the most relevant dose metric for acute nanoparticle lung toxicity (Brown et al., 2001; Hamoir et al., 2003; Landkocz et al., 2017; Longhin et al., 2016; Sager and Castranova, 2009; Schmid et al., 2009; Schmid and Stoeger, 2016; Strak et al., 2010). The toxicity of the particles is associated to the chemical compounds that are attached to them. Several of these compounds have been classified by the IARC in the Group 1 carcinogens, and among these PAHs and some metals (As, Cd, Ni) can be considered major contributors to human exposure through the respiratory tract.

1.2. Exposure at school

Mediterranean cities are recognized to be densely trafficked cities suffering from higher levels of $PM_{2.5}$ than those characteristic of Northern Europe (Eeftens et al., 2012; Querol et al., 2004). Moreover, such cities are also densely populated, thus citizens live generally close to main roads and are exposed to exhaust and non-exhaust vehicle emissions. Such high degree of urbanization also causes short distance from schools to major roads leading to non-negligible near-road pollution exposure at schools of children as evidenced by the international UPTECH (Ultrafine Particle from Traffic Emission on Children Health; (Crilley et al., 2014; Mazaheri et al., 2014) and BREATHE (BRain dEvelopment and Air polluTion ultrafine particles in scHool childrEn; (Minguillón et al., 2015; Reche et al., 2015; Reche et al., 2014b; Reche et al., 2014a) projects. Indeed, children are the most vulnerable population in terms of air pollution exposure (Brent and Weitzman, 2004; Makri and Stilianakis, 2008) due to their higher inhalation rates resulting in larger specific doses than adults (Bateson and Schwartz, 2008; Ginsberg et al., 2005; Heinrich and Slama, 2007; Selgrade et al., 2008). Therefore the long exposure time in schools (children spend from 175 to 220 days and from 5 to 8 h at school (OECD, 2012) could significantly affect the overall dose received by students attending schools located near highly-trafficked urban roads. Indeed, high indoor particle concentrations may result from the significant outdoor-to-indoor infiltration of sub-micron particles (with indoor/outdoor ratios roughly varying in the 0.6–0.9 range), which depends on physical barriers of the building, type of ventilation and particle physic-chemical properties and size (Atkinson et al., 2010; Chen and Zhao, 2011; Fuoco et al., 2015b; Health Effects Institute, 2013; Lanzinger et al., 2016; Ostro et al., 2015; Rivas et al., 2015; Stabile et al., 2017b; Stabile et al., 2016; Stafoggia et al., 2017; Stephens and Siegel, 2012; Sunyer et al., 2015; Tippayawong et al., 2009; Viana et al., 2011; Zhu et al., 2002; Zhu et al., 2005).

1.3. Aims of the work

A number of papers were published by the scientific community in terms of indoor particle concentration of PM_{10} and $PM_{2.5}$ at schools (Blondeau et al., 2005; Brunekreef et al., 1997; Diapouli et al., 2007; Heudorf et al., 2009; Tippayawong et al., 2009), in particular, PM_{10} concentrations were found to exceed most of the time the WHO guidelines (Lee and Chang, 2000; Mejía et al., 2011; Mi et al., 2006; World Health Organization, 2006). On the contrary, the scientific bibliography reporting the exposure to UFPs in schools is still scarce (Buonanno et al., 2013; Morawska et al., 2009; Reche et al., 2014b; Zhang and Zhu, 2012) (Baker et al., 1987; Chao and Tung, 2001; Guo et al., 2008; Gupta and David Cheong, 2007; Mazaheri et al., 2016; Poupard et al., 2005; Viana et al., 2015b; Viana et al., 2014; Zhu et al., 2005). In particular, a lack of knowledge on (i) air-quality-based studies able to evaluate the actual exposure of children at schools (Brunekreef et al., 1997; Mejía et al., 2011), (ii) corresponding airborne particle doses received by children (Buonanno et al., 2012a; Stabile et al., 2013), (iii) correlation between children exposure to airborne particles and adverse health effects, iv) evaluation of the lung cancer risk and the related effect of each particle-bounded carcinogenic compound was recognized.

To this purpose, the present study was conceived to provide results on children exposure to the different particle metrics (including the potentially promising metric of particle surface area) and to particle-bounded carcinogenic compounds in two European cities. Moreover, the daily dose in terms of lung deposited surface area received by children in classrooms was assessed as well as the estimate of the corresponding excess lung cancer risk associated with both surface area and particle mass doses.

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